International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN (P): 2249–6890; ISSN (E): 2249–8001
Vol. 9, Issue 6, Dec 2019, 653–660

STRESS CHARACTERISTICS OF NANOCOMPOSITE LAMINATES WITH EFFECT OF NANOCLAY CONTENT

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ABSTRACT

Numerical stress analysis is performed by changing the nanoclay content of nanoclay/epoxy composite laminates from 0 to 9wt.% to 6 levels. The nanoclay effect on stress analysis of nanocomposite laminates, a finite element fomulation based on the higher-order theory and the classical contact law is investigated. Nano clay/epoxy composites consist of [0/45/0/-45/-45/-45/0] $_{2S}$ laminated sequences of 20 layers thick. Analysis results show that the elastic modulus of nano composite increases as the nano clay content increases from 0 to 7wt.%, so that the contact force between nano composite laminates and impactor increases, and the deflection of nano composite and contact duration decrease. And also, at the nano clay content9wt.%, the elastic modulus becomes rather smaller, resulting in the opposite phenomenon, which results in less the contact force and greater the deflection and the contact duration. The stress characteristics show that the principal stress σ_1, σ_2 and shear stress σ_{12} are the largest on the third, second, and first layers, respectively, from the top and bottom surfaces of nano composite laminates. Thus, it should be fully reflected in the initial design considering the largest principal stress σ_1 among these.

KEYWORDS: Nanocomposite Laminates, Principal Stress, Nanoclay Content & Stress Characteristics

Received: Sep 03, 2019; **Accepted**: Sep 23, 2019; **Published**: Nov 15, 2019; **Paper Id.**: IJMPERDDEC201955

Original Article

INTRODUCTION

It is very important to select the content of nanoclay in nanoclay/epoxy nanocomposites. This content affects the static and dynamic behavior of the material. Particles and compounds inside nanocomposite have become one of many areas of interest and research in the past. Strengthening polymers by adding a small amount of nanoclays can greatly improve the mechanical properties of the original composites, attracting a lot of attention to research and industry. Never the less, so far there have been few numerical and analytical studies of the static and dynamic behaviour of nanocomposite. Most studies on the effects of low velocity on nanocomposite have been done experimentally. Wuite et al. [1] analyzed nanocomposite beams using classical laminate theory, but did not link them with Hertz's contact law [2]. And Meybodi et al. [3] used the Euler-Bernuelli beam theory and Hertz's contact law to investigate the low-velocity impact response of nanocomposite beams. However, the need for numerical analysis studies has grown, which have introduced higher-order theories to increase the accuracy of the analysis results. The higher order shear deformation theory(HSDT)[4] of plates can better represent kinematics, does not require shear correction factor used in the primary shear strain theory(FSDT)[5], and can calculate more accurate interlayer stress distribution as shown in figure 1. However, they require considerably more computational effort. Recently, Ahn [6] have studied the effect of stacking sequence and nanoclay content on macroscopic behaviour of nanoclay/epoxy composite.

In this study, for the numerical analysis on the effect of nanoclay content on the stress characteristics of nanoclay/epoxy nanocomposites, the theory of higher order shear deformation and the classical contact law are introduced. The stacking sequence of the applied nanoclay/epoxy composite is $[0/45/0/-45/-45/-45/0]_{2S}$ and takes into account the contents of the 6 nanoclay contents, i.e. 0, 1, 3, 5, 7 and 9 wt.%.

LITERATURE REVIEWS

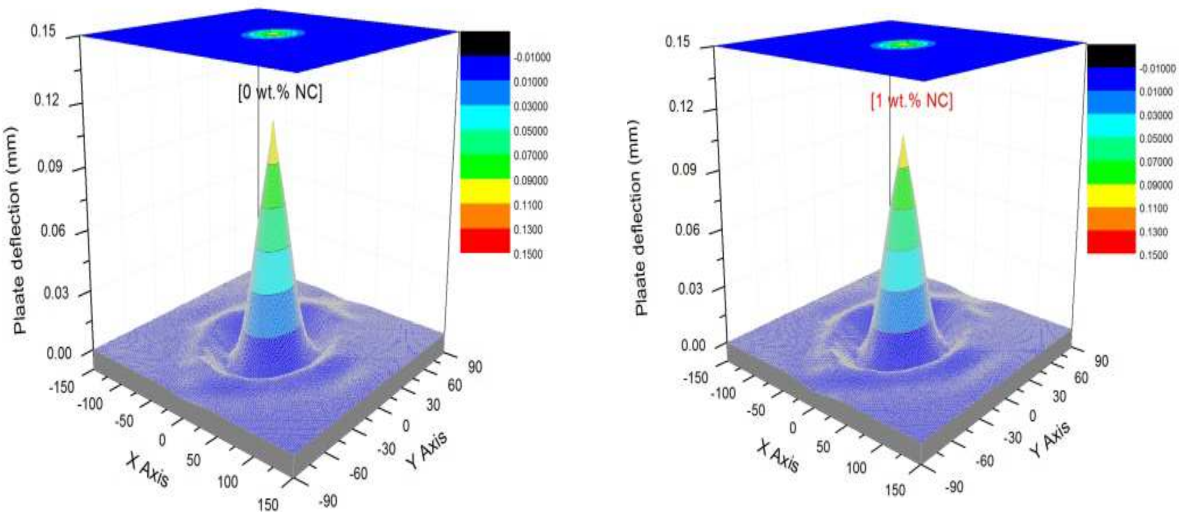
In order to study the stress behaviour of nanocomposites based on the nanoclay content at$[0/45/0/-45/0]_{2S}$ stacking sequence, six nanoclay contents inside epoxy, namely, nanoclay contents 0, 1, 3, 5, 7, and 9 wt.% are considered. The Young's modulus at different % of nanoclay is based on Chan's paper [7], and other mechanical properties are further calculated according to the MROM (the modified rule of mixture) as shown in table 1 of Ref. [6]. MROM presented by Kollar and Springer [8] is introduced to calculate the equivalent properties of the nanocomposite, which provides more accurate transverse properties than the rule of mixture (ROM). That is, MROM denotes as follows:

$$
\begin{aligned}
&E_{11}=E_f*V_f+E_{eq,m}*V_{eq.m}\\
&E_{22}=[\sqrt{V_f}/(\sqrt{V_f}*E_f+(1-\sqrt{V_{eq.m}})*E_{eq,m})+(1-\sqrt{V_{eq,m}})/E_{eq,m})]^{-1}\\
&G_{12}=[\sqrt{V_f}/(\sqrt{V_f}*G_f+(1-\sqrt{V_{eq.m}})*G_{eq,m})+(1-\sqrt{V_{eq,m}})/G_{eq,m})]^{-1} \qquad (1)\\
&v_{12}=v_f*V_f+v_{eq,m}*V_{eq.m}\\
&v_{21}=v_{12}*E_{22}/E_{11}
\end{aligned}
$$

where E, G and V are *e*lastic modulus, shear modulus and *v*olume fraction, respectively. And the subscripts f and eq, m mean fiber and equivalent properties of nanocomposite laminate, respectively.

RESULTS AND DISCUSSIONS

The analysis results of this study are shown in figure 1, and the data that is compiled from these are well presented in figure 2. Figure1 shows 3D shapes of plate deflection of nanocomposites at stacking sequence $[0/45/0/-45/0]_{2S}$ and different % of nanoclay. From figure 2, it can be seen that the greater the rigidity of between 0 to 7 wt.%, the greater the contact force but the smaller the deflection and contact duration become. However, in the 9 wt.% range, the opposite phenomenon occurs because the rigidity is smaller.



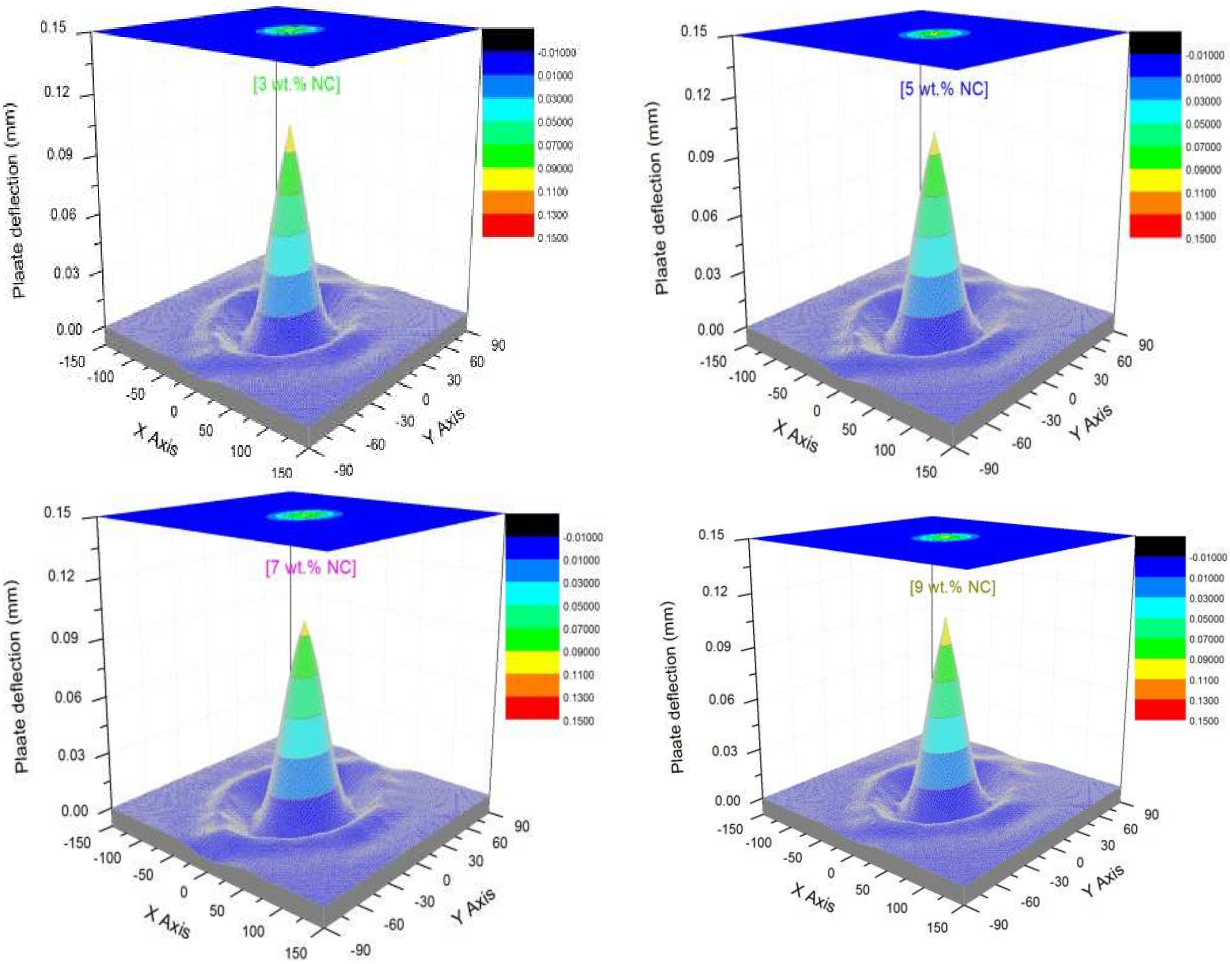


Figure 1: 3D Shapes of Plate Deflection of Nano Composites at Stacking Sequence [0/45/0/-45/0]2S and Different % of Nano Clay.

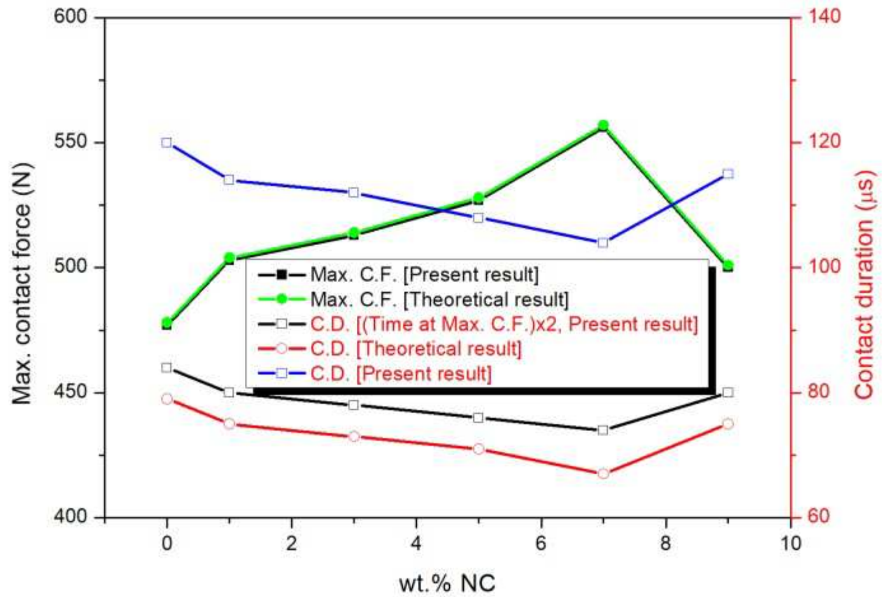


Figure 2: Comparison of Max. Contact Force and Contact Duration Between Present and WPM Results at Stacking Sequence $[0/45/0/-45/0]_{2S}$ and Different % of Nanoclay

Figure 3 shows the histories of stresses (a) σ_x, (b) σ_y and (c) σ_{xy} of nanocomposites at stacking sequence $[0/45/0/-45/0]_{2S}$ and different % of nanoclay. It is shown that the larger the wt.% NC, the greater all of stress on the up and down surfaces, but at the surface where maximum stress occurs, the smaller stressσ_1, and the greater σ_2 and σ_{12}. Figure 4 depicts 3D shapes of principal stress σ_1 of nanocomposites at stacking sequence $[0/45/0/-45/0]_{2S}$ and different % of nanoclay. Figure 5 shows the variations of stresses (a) σ_1, (b) σ_2 and (c) σ_{12} through the thickness of nanocomposites at stacking sequence $[0/45/0/-45/0]_{2S}$ and different % of nanoclay. The stress analysis shows that the principal stress σ_1, σ_2 and shear stress σ_{12} are the largest on the third, second, and first layers, respectively, from the top and bottom surfaces of the material. And the principal stress σ_1 is the largest of these, so it should be considered when designing.

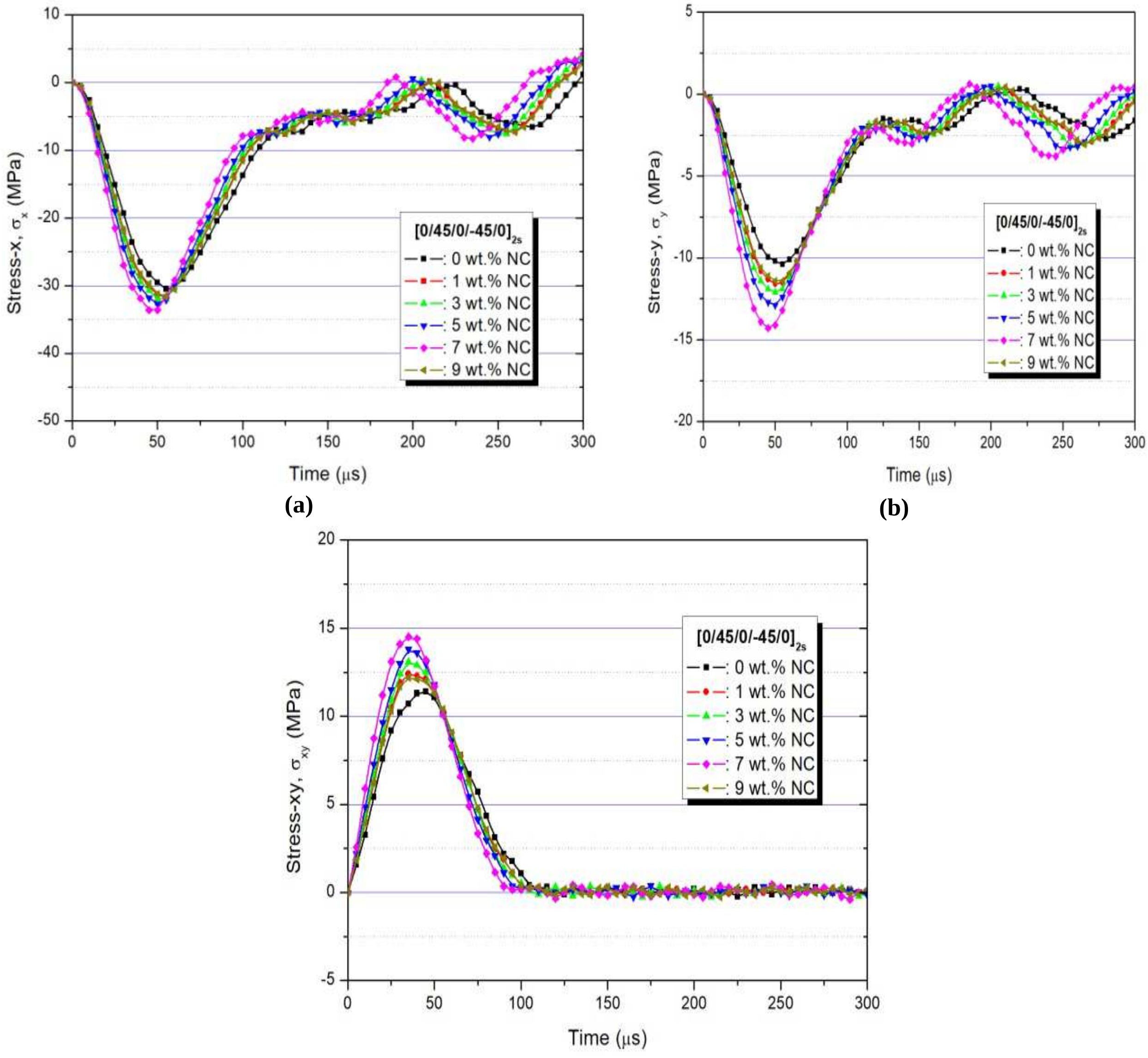


Figure 3: Histories of Stresses (a) σ_x,(b) σ_y and (c) σ_{xy} of Nanocomposites at Stacking Sequence $[0/45/0/-45/0]_{2S}$ and Different % of Nanoclay

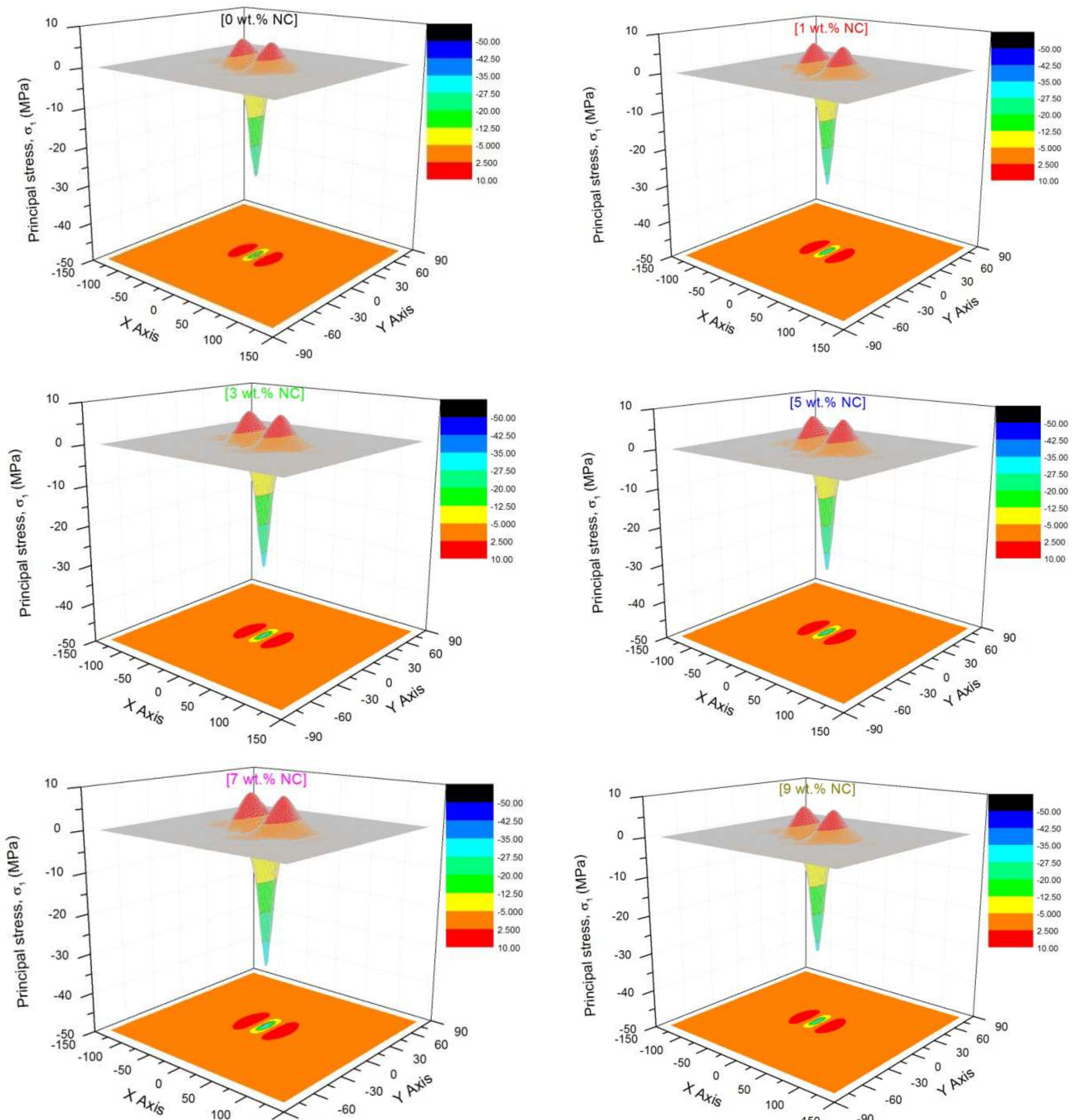


Figure 4: 3D Shapes of Principal Stress σ_1 of Nano Composites at Stacking Sequence $[0/45/0/-45/0]_{2S}$and Different % of Nano Clay

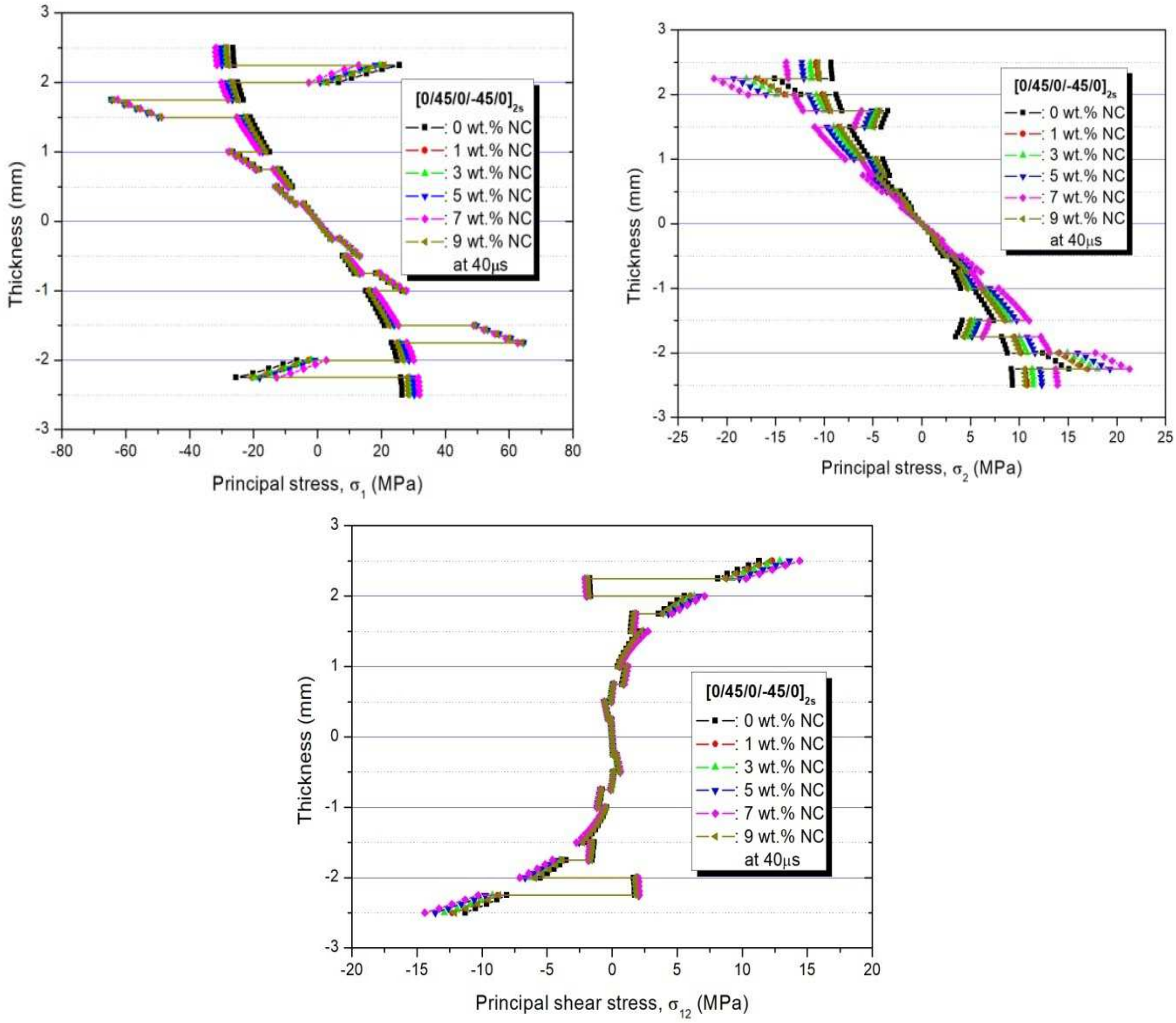


Figure 5: Variations of Stresses (a) σ_1, (b) σ_2 and (c) σ_{12} Through the Thickness of Nano Composites at Stacking Sequence $[0/45/0/-45/0]_{2S}$ and Different % of Nano Clay

CONCLUSIONS

It is very important to select the content of nanoclay in nanoclay/epoxy nanocomposites. This content affects the static and dynamic behavior of the material. In this study, for the numerical analysis on the effect of nanoclay content on the stress behavior of nanoclay/epoxy nanocomposites, the higher-order theory and the classical contact law are introduced. The stacking sequence of the applied nanoclay/epoxy composite is $[0/45/0/-45/-45/-45/0]_{2S}$ and takes into account the contents of the 6 nanoclay contents, i.e. 0, 1, 3, 5, 7 and 9 wt.%.

Studies show that with the increase of nanoclay content from 0 to 7wt.%, the strength of nanocomposite materials increases, so that the contact force between nanoclay composite and impact or increases, but the contact duration with the deflection of nanocomposite decreases. In addition, we can see that the strength of the nanoclay content is somewhat smaller compared to 7% wt.% at 9 wt.%, which results in less the contact force, and the opposite phenomenon of greater deflection and contact duration of nanocomposite. The stress characteristics also show the greatest principal stress σ_1, σ_2 and shear stress σ_{12} on the 3rd, 2nd and 1st layers from the top and the bottom of the nanocomposite laminates, respectively. Therefore, considering the largest principal stress σ_1 among these, the initial design should be fully reflected.

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